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TRAINING EFFECTIVENESS OF PLATFORM MOTION:  
REVIEW OF MOTION RESEARCH INVOLVING THE ADVANCED  
SIMULATOR FOR PILOT TRAINING AND THE SIMULATOR  
FOR AIR-TO-AIR COMBAT

By

Elizabeth L. Martin

OPERATIONS TRAINING DIVISION  
Williams Air Force Base, Arizona 85224

February 1981

Final Report

Approved for public release; distribution unlimited.

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This final report was submitted by the Operations Training Division, Air Force Human Resources Laboratory, Williams Air Force Base, Arizona 85224, under Project 1123, with HQ Air Force Human Resources Laboratory, Brooks Air Force Base, Texas 78235. Dr. Elizabeth L. Martin was the Principal Investigator for the Laboratory.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

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MARTY R. ROCKWAY, Technical Director  
Operations Training Division

RONALD W. TERRY, Colonel, USAF  
Commander

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFHRL-TR-79-51	2. GOVT ACCESSION NO. AD-A095	3. RECIPIENT'S CATALOG NUMBER 930
4. TITLE (and Subtitle) TRAINING EFFECTIVENESS OF PLATFORM MOTION: REVIEW OF MOTION RESEARCH INVOLVING THE ADVANCED SIMULATOR FOR PILOT TRAINING AND THE SIMULATOR FOR AIR-TO-AIR COMBAT		5. TYPE OF REPORT & PERIOD COVERED (9) Final reptas
7. AUTHOR(s) Elizabeth L. Martin		6. PERFORMING-ORG-REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Operations Training Division Air Force Human Resources Laboratory Williams Air Force Base, Arizona 85224		8. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS HQ Air Force Human Resources Laboratory (AFSC) Brooks Air Force Base, Texas 78235		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62205F (16) 11230114 (17) 01
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE February 1981
		13. NUMBER OF PAGES 32
		15. SECURITY CLASS. (of this report) Unclassified
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited.		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)  platform motion      flying training transfer of training      Advanced Simulator for Pilot Training (ASPT) training effectiveness      Simulator for Air-to-Air Combat (SAAC) flight simulator      motion simulation		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  This report presents a summary review of the transfer-of-training studies conducted by the Operations Training Division of the Air Force Human Resources Laboratory investigating the training effectiveness of six-degrees-of-freedom platform motion cueing. A total of six studies are reviewed. Of the six studies, five were conducted on the Advanced Simulator for Pilot Training (ASPT) located at Williams AFB and one on the Simulator for Air-to-Air Combat (SAAC) located at Luke AFB. Tasks investigated included basic and advanced contact, instruments, basic fighter maneuvers, and conventional weapons delivery. The review of each study contains a statement of objectives, a summary of the method and results, a data excerpt representative of the findings, and a critique. The report also contains a description of the research strategy from which the studies were derived, a		

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discussion of transfer-of-training methodology, and a discussion of the relationship between the results of these six studies and research findings from other agencies or facilities. Implications for future research are discussed.

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## SUMMARY

### Objective

The objective was to summarize the platform-motion transfer-of-training research conducted on the Advanced Simulator for Pilot Training (ASPT) and the Simulator for Air-to-Air Combat (SAAC).

### Approach

The rationale from which the individual studies were derived is presented, followed by a summary of the research efforts. Six transfer of training studies are reviewed. Each study review contains a brief description of the methodology and results followed by a short discussion of factors pertinent to that study. A table containing a portion of the representative data from each study is included at the end of each study summary. The final portion of the report includes a brief discussion of the implications of this research relative to the training value of platform motion, previously existing data, and directions for future research.

### Specifics

Of the six studies reviewed, five were conducted on the ASPT and one on the SAAC. For all studies, the independent variable was the presence or absence of platform motion cueing during the simulator training phase. The dependent variables for all studies were pilot performance in the simulator and performance in the aircraft. A brief summary of the characteristics of the studies reviewed and the results obtained follow:

*Study I: Basic Contact.* Twenty-four pre-flight UPT students served as subjects (8 Motion, 8 No-Motion, 8 Control). The Motion and No-Motion groups were instructed on over 20 basic contact and transition tasks in 10 ASPT sorties. The tasks included turns, climbs and descents, takeoff, normal overhead pattern, power-on stalls and traffic pattern stalls. Transfer was evaluated on two special T-37 aircraft evaluation flights and task frequency data collected up to solo. Findings indicated: (a) significant learning by both experimental groups during simulator training; (b) no performance differences in simulator or aircraft as a function of platform motion; (c) simulator groups performed significantly better than the control group.

*Study II: Aerobatics.* Thirty-six post-solo UPT students served as subjects (12 Motion, 12 No-Motion, 12 Control). Instruction in the ASPT was given on four basic aerobatic tasks (3 ASPT sorties) and four advanced aerobatic tasks (2 ASPT sorties). ASPT training blocks were separated by the corresponding T-37 aircraft instructional blocks. Finding indicated significant learning on seven of eight tasks during simulator training but significant transfer of training on only one of the eight tasks, the Barrel Roll. There were no effects on learning due to the use of platform motion.

*Study III: UPT Syllabus.* Sixteen T-37 phase UPT students (4 Motion, 4 No-Motion, 8 Control) served as subjects. The students in the Motion and No-Motion groups participated in an experimental syllabus throughout the T-37 phase and received instruction in the ASPT on every major phase of flight. The simulator and flight instruction alternated in block fashion. The Control group did not receive any ASPT training. Significant transfer of training to T-37 flying was observed in all areas but there were no differential effects attributable to the use of platform-motion cueing.

*Study IV: Motion — Visual Interaction.* Twenty-four pre-flight T-37 phase UPT students served as subjects. The experimental treatments consisted of crossing the presence vs. absence of platform motion with a full ASPT field-of-view (FOV) vs. a limited (look ahead) field-of-view. Thus, there were four experimental groups (No-Motion/full FOV, No-Motion/limited FOV, Motion/full FOV, Motion/limited FOV) with eight students per group. There was no Control group in this study. Instruction in the ASPT was given on four basic flight tasks over four ASPT missions. Transfer of skill evaluations were made on the second T-37 mission. Findings indicated that the Motion groups (regardless of FOV conditions) performed better than the No Motion groups in the simulator on three of four tasks when assessed by IP ratings, and on one task when assessed by automated scoring. There were no main effects of the field-of-view variable. Transfer of training data from the T-37 aircraft did not indicate any differences in performance due to platform motion or field-of-view.

*Study V: Basic Fighter Maneuvering.* Twenty-four transitioning F-4E pilots (8 Motion, 8 No-Motion, 8 Control) served as subjects. The G-seat and G-suit were used for both simulator groups. All basic fighter maneuvers were instructed in the SAAC with transfer evaluations in the F-4E. Results indicated significant learning during the simulator training as assessed by IPs, but no significant transfer of skills to the aircraft.

*Study VI: Air-to-Surface.* Twenty-four pilots (8 Motion, 8 No-Motion, 8 Control) between fighter lead-in school and operational equipment training served as subjects. The experimental groups received training on conventional bomb deliveries (10, 15, 30) in the ASPT (configured as a T-37). The G-seat was used for both simulator groups. All three groups received two transfer of training sorties in the F-5B in which live ordnance was delivered on each task. Results revealed significant transfer of training effects as the result of the simulator training but no effects due to platform motion.

## Conclusions

It is concluded that the addition of task correlated platform motion cueing results in negligible transfer of training for initial jet piloting skills. The potential enhancement of platform-motion cueing on skill in the advanced contact/tactical domain (e.g., air-to-air, nap-of-the-earth flight) remains to be addressed. Based upon the available data, it would seem unlikely that existing platform systems would significantly enhance transfer of training in these areas.

The implications of these conclusions are twofold: (a) existing data do not support procurement of sophisticated six-post synergistic platform-motion systems for pilot contact skill acquisition; and (b) existing simulators for pilot training possessing synergistic platform-motion systems can be equally effective if the motion system is not used. Both of these outcomes would result in substantial cost savings.

# PREFACE

This report represents a portion of the research program of Project 1123, USAF Flying Training Development, Mr. James F. Smith, Project Scientist, Task 112301, Development of Performance Measurement Techniques for Air Force Flying Training, Dr. Elizabeth L. Martin, Task Scientist.

The author would like to express appreciation to James F. Smith and Dr. Wayne L. Waag for their invaluable assistance in the preparation of this report.

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REVIEW OF MOTION RESEARCH INVOLVING THE ADVANCED  
SIMULATOR FOR PILOT TRAINING AND THE SIMULATOR  
FOR AIR-TO-AIR COMBAT

I. INTRODUCTION

Scope

The purpose of this report is to summarize and integrate the findings of several motion/training research efforts which have been conducted by the Operations Training Division of the Air Force Human Resources Laboratory (AFHRL/OT). In addition, an attempt is made to integrate these findings with the results of other motion/training research. Non-training related research efforts concerned with the design and definition of engineering requirements and characteristics of the various motion-cueing systems are not considered here. A comprehensive review of transfer-of-training research involving manipulations of visual and kinesthetic cues with associated data on training effectiveness is presented in a recent report by Waag (1980).

A total of six transfer-of-training studies are reviewed comparing the presence versus absence of platform motion pretraining on subsequent performance in the aircraft. Five of these studies were conducted on the Advanced Simulator for Pilot Training (ASPT) located at Williams AFB. One study was conducted on the Simulator for Air-to-Air Combat (SAAC) located at Luke AFB. Each study review contains a summary of the methodology, the results, and a table containing data excerpts which are representative of the findings.

Research Strategy

Products of modern engineering simulation technology include a variety of devices intended to simulate vestibular/kinesthetic cues present in actual flight. Currently available systems include synergistic six-degrees-of-freedom (6 DOF) platforms, G-seats, G-suits, and limited special effects packages, such as cockpit and stick shakers. In addition, non-kinesthetic motion cues are presented through the visual modality via instrument displays and external visual displays (if present).

Research efforts need to address the problems of the user or potential user. The user wants to know which options to buy and how to use them (with emphasis on the former). At the present time, the research information available to answer these questions is limited in scope and volume. The assumption was made at the outset, that a comprehensive research program would continually lag behind the needs of the users; therefore, a research strategy should be adopted which would provide the most information in the shortest time frame. (For an excellent discussion of the problems involved in the design/use cycle of synthetic flight trainers, see Caro 1977b). The research strategy which evolved can best be characterized as a critical dimensions approach. The initial step involved identification of the critical dimensions along which the impact of motion cueing might be expected to be significant. The next step involved identification of what previous research had been accomplished and what major areas had not been addressed. The final step involved matching the areas which needed to be investigated with the research facilities available to the Operations Training Division. Within any one effort, the goal was to compare the most costly configuration with the least costly configuration. In the event that one configuration was found

superior to another, subsequent research would compare the superior condition to some intermediate (in terms of cost) configuration. If, on the other hand, the initial finding did not reveal a difference between the most and least costly configurations, subsequent research would focus on a different combination of factors. Although this type of research strategy involves a higher level of risk than does the more time-consuming parametric approach, it was decided that a series of relatively simple studies could provide a broader scope of information within a given time frame.

Three factors were identified as representing the most important variables for motion research: (a) aircraft type, (b) task/mission type, and (c) level of pilot experience. It was apparent that little research had been done in the area of skill acquisition, maintenance, or retention of *contact* tasks and that very little transfer-of-training motion research had been accomplished. It was also evident that most of the training relevant research had used 2 or 3 DOF motion platform systems, not the 6 DOF systems currently available as the off-the-shelf option.

The studies summarized in the report represent an attempt to fill in some of the gaps between the engineering development phase and the operational implementation phase. This report does not purport to contain "the answer" regarding platform motion. Certainly far more areas have been identified for research than have been addressed to date and the reader should be cautious in any attempts to extrapolate beyond the body of existing information.

The remainder of this report is devoted to a summary of each study, a discussion of the studies individually and collectively, and conclusions. Where necessary, discussions of experimental design factors have been included. Because each of the studies is a transfer-of-training experiment, a short discussion of the basic design of transfer-of-training experiments and problems typically encountered is presented in the next section.

## II. THE TRANSFER-OF-TRAINING EXPERIMENT

### General

Will practice in a flight simulator help performance in the aircraft? Does the addition of platform motion increase the effectiveness of simulator training? The transfer-of-training paradigm addresses the general issue of how practice on one task influences performance on another task. There are three basic possible outcomes: (a) positive transfer (practice on A improves performance on B), (b) negative transfer (practice on A interferes with performance on B), and (c) no transfer (practice on A does not affect performance on B). Each of the effects is determined by a comparison with performance on B without any preceding practice on A. The performance on B alone establishes a baseline of what can normally be expected. There are a number of theories which attempt to explain why transfer effects occur. Without digressing into the theoretical models, a good operating assumption for predicting positive transfer is that the more similar the stimulus and response "elements" are in A to those of B, the greater the probability of maximizing positive transfer. Although there are a few situations which can be expected to produce negative transfer, most research in flying simulation training is concerned with optimizing the likelihood of positive transfer from the simulator to the aircraft. This assumption has been the driving philosophy behind the demand for high fidelity flight simulators (i.e., attempting to match the two physical environments as closely as possible).

There are a number of ways to structure a transfer-of-training experiment. The one chosen depends on the specific items of interest and the resources available. There are two experimental designs most commonly used in flying training transfer-of-training studies. The basic difference between them is in the basis used to assign subjects to groups. In one case (Design A), subjects are assigned randomly to groups. In the other case (Design B), the subjects are given a pretest on some task related to the criterion task and are assigned to groups according to the pretest scores. The pretest technique is used in an attempt to

assure the groups are of equal ability at the beginning of the study. The use of the pretest technique is desirable if a valid pretest is available, particularly when a small number of subjects are to be used. The two designs are as follows:

#### DESIGN A

Pretest	Group	Pretrain	Evaluate
None	Experimental Control	Simulator No Simulator	Aircraft Aircraft

#### DESIGN B

Pretest	Group	Pretrain	Evaluate
Tracking Task Score	Experimental Control	Simulator No Simulator	Aircraft Aircraft

These are the basic designs for the evaluation of only one factor, commonly used for simple "simulator versus no-simulator" training effectiveness studies.

The question of interest in this report concerns the relative transfer effects of pretraining with platform motion versus those without platform motion. In addition to the motion/no-motion comparison, the level of simulator training effectiveness needs to be established. This is accomplished by adding a third group to the design. This group, usually designated the control group, does not receive the experimental simulator treatment but only the operational syllabus currently being used. The paradigm for this design is as follows:

Group	Pretrain	Evaluate
Experimental	Simulator/Motion	Aircraft
Experimental	Simulator/No Motion	Aircraft
Control	No Simulator	Aircraft

This design was used in five of the studies reviewed in this report.

The intent of a transfer-of-training experiment is to investigate whether practice on the pretraining task influences performance on the criterion task. It is, therefore, important to establish that skill acquisition took place during the pretraining phase. If no skill acquisition occurred during the pretraining phase, there is nothing to be transferred. Performance during pretraining should be measured at least twice (the beginning and end) in order to establish that there was some acquisition of the skill to be transferred.

In almost every respect, the factors which make a good transfer-of-training experiment are the same factors which make any experiment good. The following discussion will consider those aspects which are most germane to transfer-of-training studies conducted in the realm of flying training research.

#### Asking the Question and Task Selection

The design of a valid experiment usually requires a precise specification of the research question.

Operational training questions are usually posed using global concepts such as "motion" or "aircraft performance." From these concepts, a specific subset of representative factors need to be selected, i.e., what kind of motion or what kind of tasks? Do the tasks selected represent the intent of the original question? For example, if one is interested in the training effects of flight simulator platform motion on the acquisition of flying skills, one should not study the behavior of experienced pilots in the simulator only.

### Subjects

The sample of subjects used in a study should be representative of the population to which one wants to generalize the findings. This is particularly a problem when a study is to be run on a basis of non-interference with normal operations. The available subjects may be the first ones to complete some prerequisite training which may mean they are in the top ability level. The other major problem is determining how many subjects should be used. The concern in this respect is not having enough subjects available. The minimum number of subjects required is a function of a number of factors, one of which is the true magnitude of the effect that is under investigation. The smaller the magnitude of true effect, the larger the sample size required to obtain a statistically significant difference. The desire or demand to limit the amount of interference with normal flying operations usually dictates a smaller than desirable sample size. Although there is no hard-and-fast rule, a sample size of 15 to 20 should be sufficient in most cases, and a sample as small as four may be sufficient if there is a large degree of experimental control possible and if the factor under investigation has a large and consistent effect on performance.

### Performance Measurement

The problems associated with performance measurement usually make it the weakest portion of most flying training TOT studies. Ideally, the validity, reliability, and resolution of the measurement techniques used in a study should be determined prior to use in the study, however, this is typically not accomplished (see Koonce, 1974 for an exception). Reliance on instructor pilot (IP) performance ratings is the most common source of performance assessment in the aircraft. There are two reasons why IP measurements are typically used. (a) the IP will be the only available source of performance measurement, particularly in aircraft performance evaluation, and (b) IP evaluations are viewed as being the most operationally valid source of information. However, without independent research to establish the degree of reliability and resolution of their judgements, the data are subject to unknown sources of variance and potential biases.

## III. TRANSFER-OF-TRAINING STUDIES

### Study 1: Motion vs. No Motion — Basic Contact (Martin & Wang, 1978a)

The objective of this study was to assess the degree to which simulator pretraining with motion cues (provided by a synergistic 6 DOF motion platform) facilitated the acquisition of basic contact and runway oriented tasks. The study was conducted on the ASPT using pre-flight T-37 undergraduate pilot training (UPT) students.

## Method

Three groups of eight students participated in the study. Two experimental groups received pretraining in the ASPT using the same training syllabus. The only difference between the training for these groups was the presence or absence of platform motion cueing during the ASPT training sessions. The third group received training according to the standard syllabus (which included pretraining on basic tasks in the fixed-based non-visual T-4 instrument flight trainer). The groups were designated M (motion), NM (no motion), and C (control).

The ASPT pretraining consisted of 10 simulator sessions covering instruction on some 20 contact tasks. There were essentially two types of tasks. (a) basic airwork tasks (e.g., straight-and-level, constant airspeed climbs and descents, 30° and 60° level turns, slow flight, and configuration changes) and (b) runway oriented tasks (e.g., takeoff, straight-in approach and landing, touch-and-go, and normal overhead pattern). Power-on stalls and the traffic pattern stall series were also taught. A fixed-trial training technique was used in which all subjects practiced each task the same number of times. Automated pilot performance measures and instructor pilot ratings of proficiency were obtained periodically throughout the 10 ASPT sessions.

Assessment of the ASPT pretraining and the relative contributions of platform motion cueing during this pretraining consisted of airborne instructor pilot evaluation of student performance. Two types of evaluations were conducted. (a) two special aircraft missions early in training designed to assess short-term transfer effects and (b) task frequency data collected on all missions through the solo sorties (approximately 20 flights). The special flights took place on the first and fifth aircraft rides and were designed to include all tasks taught during the ASPT pretraining phase. These rides were given only to students in the experimental (M and NM) groups, allowing only for a comparison between the M and NM conditions and not for a more general assessment of short-term effectiveness of the pretraining. The IP's rated student performance on a 12-point expansion of a unsatisfactory, fair, good, excellent (U, F, G, E) scale (+/-). The indications of long-term transfer effects were provided by task frequency data collected on eight of the more advanced tasks. This information included the number of repetitions per flight and the proficiency level on a four-point scale (U, F, G, E) of each repetition. This information was collected on members of all three groups.

## Results

*ASPT Training.* There were no consistent differences between the motion and no motion groups during the simulator phase based on IP assessments and automated error scores. Performance measures were collected on approximately half of the tasks, thus, the possibility remains that there may have been some differences on the other tasks.

The second main finding was a generally consistent learning effect reflected in both the IP ratings and the root mean square (RMS) scores. The learning effect was not evident on a few basic tasks but this was probably due to the fact that student performance was almost operationally proficient from the beginning. The demonstrated learning is important to the overall experiment since it provides positive evidence that the students did indeed acquire some skills during the pretraining phase. (If learning had not been demonstrated, a subsequent no-difference finding in the aircraft could be attributed to ineffective pretraining.)

*Transfer Effects.* Performance in the aircraft can also be characterized by two main findings. (a) no consistent difference between the motion and no motion conditions and (b) the performance of the two groups trained in the ASPT was rated higher than that of the control group.

All tasks taught in the ASPT were evaluated in the aircraft on the first and fifth sorties (including the Overhead Pattern and Landing, Straight-In Approach and Touch-And-Go, and Power-On and Traffic Pattern Stalls at Altitude). There were no statistically reliable trends, or even non-significant trends favoring one group over the other. Since data on the first and fifth sorties were not collected on the control group, it is not possible to assess the magnitude of the short term benefits of the ASPT pretraining syllabus. In general, performance on the basic tasks was rated in the good to excellent range while performance on the more advanced tasks was more variable, ranging from unsatisfactory-plus to excellent. Average performance levels on these tasks were in the fair range.

Analysis of the task frequency data collected on eight of the more advanced tasks did not reveal any reliable differences between the motion and no motion conditions. The performance of each of the two groups was superior to that of the control group on all of these tasks even for tasks involving a considerable time delay between ASPT training and T-37 training. The effect was the smallest for the tasks with the longest delay interval: power-on and traffic pattern stalls. These tasks were also practiced the least number of times prior to solo (termination point for data collection). Thus, although there was significant positive transfer from the ASPT to the T-37, there was no differential impact on the transfer as a function of motion condition.

Table 1 presents the mean of the group performance on each of the tasks for which task frequency data were collected. The IP rated the student's performance on a U, F, G, E scale for each repetition of each task on every sortie until solo (approximately 20 flights). These grades were assigned 1, 2, 3, 4 values, respectively, and an overall mean grade was computed. The higher the score, the better the performance level. (The fact that these scores tend to be low simply reflects the relatively greater emphasis on initial skill acquisition for beginning pilots). The performance of the two ASPT groups combined was reliably better than that of the control group for each case. None of the differences between the Motion and No Motion groups was found to be significant.

*Table 1. Task Frequency Summary: Study I  
(Mean IP Ratings)*

Maneuver	Motion	No-Motion	Control
Takeoff	2.50	2.58	2.11
Straight-In Approach	2.23	2.10	1.83
Landing (Straight-In Approach)	1.84	1.72	1.51
Overhead Pattern	2.01	1.98	1.61
Landing (Overhead Pattern)	2.08	2.25	1.86
Slow Flight	2.72	2.53	1.79
Power-On Stalls	2.20	2.15	1.75
Traffic Pattern Stalls	2.09	1.91	1.43

Study II: Motion vs. No Motion — Aerobatics (Martin & Wang, 1978b)

The previously discussed study focused on the acquisition of basic contact and transition skills in the novice pilot. The present study focused on the acquisition of basic and advanced aerobatic tasks in the post-solo UPT student. Accomplishment of these tasks involves considerably more skill on the part of the student pilot. These tasks also involve motion cues of greater magnitude than those in the first study. In addition, more translational cues are involved in these tasks. Although the aerobatic phase of the T-37

program is not heavily emphasized (aerobatics are considered primarily as a confidence building element, and a high level of skill is not required), it was hoped that studying the contributions of platform motion cues to the acquisition of these types of tasks would have greater relevance to flying training programs in the fighter/attack area.

## Method

A transfer-of-training paradigm was used in which students were given pretraining in the ASPT on selected aerobatic tasks either with or without the presence of platform motion cueing. As in the first study, the G-seat was not used, the full visual scene was available, and a fixed trial training technique was employed. In addition to the two experimental ASPT groups, a standard syllabus control group was included. There were 12 student pilots assigned to each group.

The ASPT pretraining syllabus contained two blocks of instruction, each followed by aircraft instruction and performance evaluation (transfer-of-training assessment). The first block of ASPT training consisted of three simulator missions of instruction and practice on four basic aerobatic maneuvers (Loop, Aileron Roll, Split-S, Lazy-8). The second block of ASPT training included instruction on four advanced tasks (Barrel Roll, Cloverleaf, Cuban 8, Immelman) administered in two simulator missions.

Following each block of ASPT instruction, the students entered the corresponding block of aircraft instruction. The basic block of aircraft instruction consisted of four sorties. The advanced block also consisted of four sorties but one of these sorties was a solo mission. Instruction during these blocks included the tasks taught in the ASPT as well as the introduction of several other new tasks and review of previously introduced, but not mastered, contact tasks. The experimental design called for one repetition of each task on each sortie for the relevant instructional block. Thus, a complete data return would have four trials of each of the basic tasks and three trials of each of the advanced tasks.

Pilot performance was assessed by the instructor pilot in the cockpit. Since the ASPT automated performance measurement system did not include a full set of aerobatic scenarios, special data cards were developed for use by the IP in recording specific system state parameters at specific criterion points in each task. In addition to recording specific parameter values, the IPs were asked to supply an overall task performance rating on a 12-point scale (the operational 4-point scale expanded to include "plus" and "minus" options in each category).

Although similar to the first study in basic methodology, it was not possible to exercise an equivalent amount of control over ASPT instruction or aircraft performance evaluation. It is not apparent that these problems resulted in a bias in either the motion or no motion direction but it is clear that the lack of control decreased the effectiveness of the ASPT instruction, resulted in a loss of information on transfer assessment, and increased the amount of "noise" in the data that were obtained.

## Results

*ASPT Training.* Analyses of IP ratings (using a 12-point scale) revealed significant improvement on all tasks except the Lazy-8 but no differences on any tasks between the Motion and No Motion conditions.

Considering the comparison between the motion and no motion groups on the four basic aerobatic tasks taught during the first phase, there were no overall tests of significance which met the required confidence level ( $p \leq .05$ ). In the set of the four advanced aerobatic tasks, there were reliable differences on the first measured Immelman trial and the second measured Cloverleaf trial. On the



Immelmann, the motion group did better on pitch-rated values while the no motion group did better on desired bank values. On the Cloverleaf, the motion group did better on rated bank control. There was no trend for one group to perform consistently better than the other on any given aspect of control skill across maneuvers.

*Transfer Effects.* Of the eight tasks included in the study, significant training/transfer effectiveness (as indicated by an overall multivariate test) was obtained on only one task, the Barrel Roll. Within this task, there were no differences between the motion and no motion conditions, although both groups did better than the control group. (Unfortunately, overall performance ratings were not available for the aircraft evaluation phase due to unacceptable levels of inter-rater reliability obtained during IP data collection training.)

A number of procedural/methodological deficiencies in the study may account for overall low level of simulator pretraining effectiveness. It would, thus, not be prudent to conclude that there are no potential savings possible in this skill area. However, given the lack of demonstrated effectiveness, this study does not constitute an adequate test of the motion/no motion hypothesis.

Table 2 depicts the results of the aircraft evaluation of the Barrel Roll maneuver. This was the only one of eight tasks in which a reliable positive transfer was observed. There are five parameters included for this task. The first three concern the amount of bank deviation observed at three tasks positions. The higher the number, the poorer the performance. The last two items provide the IP's judgement on a five-point rating scale of how well the student controlled the roll rate and maintained the reference point alignment. For these items, the higher the score the better the performance. None of the differences between the Motion and No Motion condition were reliable. The performance of each of the two ASPT groups was reliably superior to that of the control's for the Bank Inverted, Roll Rate Control, and Reference Point Alignment items.

Table 2. Barrel Roll/T-37: Study II  
(Mean Performance)

Parameter	Motion	No-Motion	Control
Bank-Start	2.46	5.38	4.81
Bank-Inverted	6.73	7.71	17.22
Bank-Completion	1.96	2.08	4.57
Roll Rate Control	2.58	2.92	2.04
Reference Point Alignment	2.80	2.89	2.06

#### Study III: Motion/Visual Interaction (Nataupsky, Waag, Weyer, McFadden, & McDowell, 1979)

The two previous studies dealt with the contribution of platform motion when training in the simulator was accomplished using a full field-of-view visual display. It was hypothesized that the positive effects of motion cueing may have been diminished in the previous studies due to the presence of (and the attention devoted to) the visual display. Or conversely, a restricted visual scene may enhance the positive motion effects. The present study was designed to investigate the potential interaction between the size of the visual display and the presence or absence of platform motion cues. The reader interested in a comprehensive review of visual/training research should see Wang (1980).

## Method

Thirty-two pre-flight T-37 UPT students were assigned to one of four experimental groups: (a) motion/full field of view (MFV), (b) motion/limited field of view (MLV), (c) no motion/full field of view (NMFV), and (d) no motion/limited field of view (NML). Thus, there were eight students in each group. However, there were 16 subjects for the comparisons of the main effects of motion or field of view.

The motion, no motion, and full field-of-view configurations were the same as those used in the two previously discussed studies. The limited field-of-view configuration provided a visual display of 48° vertical vs. 36° horizontal as determined from the student pilot's position. This field of view was constructed by creating a computer-controlled mask. The visual scene was essentially a look-ahead view approximating in size the display area of the Instrument Flight Simulator system scheduled for use by the Air Training Command. As in the previous studies, the G-seat was not used.

The students received an equal amount of training (fixed trial) on four tasks: (a) Takeoff, (b) 60° Bank Steep Turns, (c) Slow Flight, and (d) Straight-In Approach and Landing. Practice on these tasks was distributed over four ASPT sorties. Student performance was assessed on each task on each sortie by both the instructor and the automated performance measurement system.

Transfer of training was assessed on the student's first aircraft mission only. A non-ASPT trained control group was not used. This mission was designed to include at least one repetition of each task taught in the ASPT pretraining phase. The student's performance was assessed by the same IP who instructed the student during the pretraining. There were four IPs whose student assignment was counterbalanced across the experimental conditions. (These IPs had received extensive training in the use of the ASPT and the use of the performance evaluation rating scale.)

## Results

*ASPT Training.* Three sources of data were available to assess performance during the simulator training phase: (a) automated criterion-referenced values (RMS error), (b) automated control input measures (RMS movements of aileron, elevator, and throttle), and (c) overall performance ratings supplied by the IP.

There were no main effects of field of view on any of the tasks for either type of automated scoring or IP ratings. There were reliable improvements (i.e., skill acquisition) in performance across trials on all tasks.

Unlike the findings of the previous studies, there were reliable main effects of the motion factor on three of the four tasks for the overall performance evaluation by the IPs. The IPs judged the performance of the students in the Motion group (regardless of field-of-view condition) to be superior to the No Motion performances on Takeoffs, Slow Flight, and the Straight-In Approach and Landing. There was no reliable effect of motion on the Steep Turn task.

Analyses of the RMS error scores revealed that the Motion group performed significantly better on the Straight-In Approach and Landing task but not in Takeoffs, Slow Flight, or the Steep Turn tasks. Evidently, the IPs were considering (and sensitive to) factors not included in the task criterion measurements on the Takeoff and Slow Flight tasks.

Analyses of the control input data, i.e., RMS movement of aileron, elevator, and throttle, were also conducted. There were significant decreases in RMS movement scores as a function of training for all groups. There were reliable differences between the Motion and No Motion groups on the elevator input

for the Straight-In Approach and Landing such that the Motion group had higher RMS movement scores than did the No Motion group. The direction of this difference does not support the notion that the Motion group was "smoother" and is not consistent with other motion-related control input research.

It is important for the overall interpretation of these findings to note that there were no reliable interactions between the motion condition and either trials or field of view. The main effects of motion that were observed were present from the first measurement and did not increase or decrease as a function of training. In other words, the motion cueing affected the level of performance but not the rate of skill acquisition.

In summary, (a) reliable learning was observed on all tasks, (b) IPs rated the performance of the Motion group superior to the No Motion group on three of four tasks, (c) error scores were lower for the motion group on one task, (d) the RMS control input movement values decreased with practice, and (e) motion was associated with high RMS movement scores on two tasks. There was complete consistency on (a) the lack of a motion effect on the Steep Turn task, (b) the presence of a motion effect on the Straight-In Approach and Landing task, and (c) the lack of a field-of-view effect on any task.

*Transfer Effects.* The transfer evaluation was conducted on the student's first ride in the T-37 aircraft. One repetition of each of the four tasks was performed by the student and the overall performance rated on an eight-point scale by the IP.

There were no reliable difference observed between the groups on any of the four tasks although the mean performance levels for the Motion groups were slightly higher than for the No-Motion groups. Thus, although there were reliable differences observed in simulator performance, the differences did not carry over to initial aircraft performance.

Table 3 presents the mean overall performance ratings per group per task and trial for the ASPT phase and T-37 transfer evaluation. The ratings were given on an eight point scale. 1. (Unsatisfactory); 2. (Fair-); 3. (Fair); 4. (Fair +); 5. (Good-); 6. (Good); 7. (Good +); and 8. (Excellent). There was reliable improvement for both groups on all tasks. The overall difference during simulator training between the Motion and No-Motion groups was reliable for the Takeoff, Slow Flight and Straight-In Approach but not for the Steep Turn. The differences between the groups were not reliable for the aircraft evaluations.

Table 3. Mean IP Performance Ratings ASPT and T-37: Study III  
(Mean IP Ratings)

	ASPT Trials <sup>a</sup>				T-37
	1	2	3	4	1
Takeoff					
Motion	2.06	4.94	5.50	6.00	3.88
No Motion	1.31	3.50	4.94	5.06	2.56
Slow Flight					
Motion	3.25	5.88	6.50	6.50	3.31
No Motion	2.63	3.94	5.00	5.50	2.25
Straight-In Approach					
Motion	1.88	3.00	5.63	5.88	2.44
No Motion	1.38	1.94	4.50	4.63	1.94
Steep Turn					
Motion	2.69	5.19	5.38	5.25	3.06
No Motion	2.56	3.69	4.81	5.44	1.94

<sup>a</sup>Measurements were obtained periodically throughout the ASPT training phase. From one to four (depending on the task) practice trials preceded each measured trial.

Study IV: Motion vs. No Motion in a UPT Syllabus Study  
(Woodruff, Smith, Fuller, & Weyer, 1976)

This study (formally named the Operational Utilization Test) was not, by design, a part of the critical dimensions testing approach described in the introduction. The primary purpose of the study was not to experimentally assess the contributions of platform motion but rather to establish a broad range of baseline information relative to the potential application of a full mission simulator. A preliminary comparison of platform motion cueing across *all* phases of the T-37 UPT program was a secondary objective.

#### Method

An experimental syllabus was developed which integrated the use of a full mission flight simulator (the ASPT) into the T-37 phase of the UPT program with the intent of including all areas of instruction and accomplishing all of the current training objectives. The syllabus was based on a proficiency-advancement-by-block concept in which the student would receive simulator training on a particular block of tasks until judged proficient by the IP. The student would then proceed to the aircraft for the corresponding block of in-flight instruction.

Following completion of that block of tasks, the student would return to the simulator for instruction on the next block of tasks. Eight students were chosen for participation in the test. Their progress was compared with eight control students who received the standard syllabus of instruction. The primary dependent variables were time spent in the simulator and time spent in the aircraft. Four students in the test group were trained using the ASPT platform motion system while the other four did not receive platform motion cues (except for instruction in stalls, in which case platform motion cues were used). As in the earlier studies, the G-seat was not used, and the full visual display was available.

#### Results

The measures of transfer effectiveness used were the percent of time saved and computation of a transfer effectiveness ratio. While considerable flying time savings were achieved in various phases of instruction, there were no differences observed between the motion and no motion students in any of the skill areas, either in time spent in the simulator or aircraft.

This effort differs in many respects from the other studies reviewed in this report. The students had considerably more time in ASPT training (averaging almost 60 hours) compared to the other studies (which ranged from 4 to 10 hours). They were instructed on all major task areas over a long period of time. Their simulator training was continuously interspersed with aircraft training. The nature of their training was, in many respects, more operationally valid. This type of effort complements the aspects of the other studies. The other studies focused on a small number (or type) of skill/task areas and thus give a relatively molecular picture. The syllabus study, by contrast, provides a more molar view. It has been hypothesized that the magnitude of positive motion effects may be small for any given area but may become significant when summed or accumulated over a larger range of tasks. It has also been argued that the motion cues would become more beneficial as the students gain experience with the aircraft motion system and learn the relationship between inputs and kinesthetic feedback. The findings of the syllabus study do not support these notions. However, the reader should bear in mind that there were only four subjects in each condition, hardly enough to draw any definitive conclusions. The reader should also recall that other types of information such as number of practice attempts per task were not available.

Table 4 shows the ratio by training category of simulator and aircraft hours used by the four Motion students compared with the hours used by the No Motion students. The ratios were computed by dividing the average number of training hours required by students trained using simulator motion by the comparable hours used by students trained without simulator motion.

*Table 4. Ratios of Average Hours Required to Complete Training by Motion and No-Motion Group by Training Segment and Device*

Training Segment	Simulator	Aircraft
Basic and Presolo	0.93	1.02
Advanced Contact	1.11	0.95
Instruments	0.96	1.02
Navigation	0.98	1.01
Total	0.98	1.01

Note. — These ratios were obtained by dividing the hours used by the Motion by the hours used by the No-Motion group.

#### Study V: Motion vs. No Motion — Basic Fighter Maneuvering (Pohlman & Reed, 1978)

This training study was conducted on the SAAC. By virtue of an agreement between the Tactical Command and the Air Force Systems Command, this device is used for both operational training and research. The SAAC is equipped with a 6 DOF platform motion system, G-seat, and G-suit.

The study was designed to determine the training effectiveness of the SAAC 6 DOF platform motion system for the acquisition of basic fighter maneuvering skills in the F-4E. The rationale for the design of this study was slightly different than that for the UPT studies. The pilot opinion research indicated that the G-seat and G-suit were necessary for adequate realism and training. Additionally, the cues from these devices overshadowed the cues delivered by the platform system. Therefore, the G-seat and suit were always operational while only the platform on-off status was manipulated. Thus, in this study, No-Motion represents G-seat and suit on, but no platform cueing.

#### Method

Twenty-two replacement training unit (RTU) students transitioning into the F-4 participated in the study. Eight students were assigned to the motion group, eight to the no motion group, and the remaining six students served as the control group. The students were matched in their group assignment on the basis of information on their performance in UPT, fighter lead-in training, and their progress in the F-4 program prior to the study (3 to 4 aircraft missions).

Simulator training in the SAAC was given to the Motion and No-Motion groups. The Motion group received cues displayed by the platform system and the G-seat and G-suit systems. The No-Motion group received G-seat and suit cueing and no platform cueing. The simulator syllabus consisted of seven SAAC sorties. The first two missions were simulator familiarization rides. The next four missions consisted of instruction on nine basic fighter maneuvers (BFM). These tasks included Acceleration Maneuver, Hi Yo-Yo, Barrel Roll Attack, Immelmann Attack, Tactical Formation, Lag Roll, Defensive Maneuvers, Separation, Quarter Plane, and Setting Up On the Perch. Training was not based on proficiency advancement or a fixed number of trials, but was governed by time constraints; students received as much training as possible within the sortie length. These four missions were approximately 1 hour long. The

final SAAC mission consisted of a checkride on all the tasks. Throughout the study, the IP was located in the second cockpit and served both as the instructor and as the adversary.

All of the measures of pilot performance were provided by the IP and consisted of subjective ratings. The normal operational rating scale was modified from a five point (0 to 5) scale used in standard instruction to omit rarely used grades. The remaining scale was then expanded from a three point (0 to 3) scale to a nine point scale by adding "plus" and "minus" options for 1, 2, and 3. It was felt necessary to remain within the structure of the operational scale for standardization between IPs but to expand the options in order to obtain greater sensitivity to skill differences. The IP graded the performance on each task and also provided a grade for the entire mission. In addition to the task grades, a second set of variables was included for assessment. These variables were designated as Basic Fighter Maneuvering Skills and were thought to represent the more cognitive aspects of performance. This set of measures was included to allow for the possibility that SAAC training was differentially more effective in the development of cognitive skills than in actual stick and rudder skills. These variables included range estimation, target acquisition, keeping bogey in sight, weapons parameters recognition, switchology, preparation, attitude, judgement, and descriptive commentary. Analyses of the data included both item by item comparisons, as well as comparison of summary scores computed by collapsing across the items within each set (task vs. skill).

The transfer-of-training evaluation consisted of performance measures collected on four F-4 BFM sorties for all three groups. The data collected during the transfer phase were in the same format as the data obtained during the simulator training. The aircraft evaluation was conducted by the students' normally assigned IP who was not the same IP that instructed during the SAAC training.

## Results

*SAAC Training.* The results of the simulator training may be summarized as follows: (a) there was no initial task variable performance difference between the Motion and No Motion groups, (b) the No-Motion group was initially superior on the skill set of variables; (c) both groups improved during the SAAC training on the task performance, (d) the Motion group improved on the skill set; and (e) the Motion group was superior to the No-Motion group on both the task and skill variables at the end of the SAAC training phase.

The groups had been matched on the basis of performance indicators available prior to the study. Therefore, it was hoped that there would be no initial differences in performance. This goal was accomplished on the task performance. The initial superiority of the No-Motion group on the skill component was due to a small but consistent difference on all the items within the set. The fact that the No-Motion group did not show significant improvement on the skill set is not surprising considering their initial grades were near the top of the scale. The superiority of the Motion group on the task set at the end of SAAC training was due to significant differences on two of the individual tasks, the Acceleration Manuever and Quarter Plane, and small differences on the remaining tasks. Their superiority on the skill set was due to small but consistent differences on all the individual items.

*Transfer Effects.* The data collected in the aircraft were in the same format as those in the SAAC. The analyses were designed to address three questions. First, was there a difference in performance between the Motion and No-Motion groups? Second was there a difference in performance between those who received SAAC training and the Control group? Three, was there differential learning as a function of either the Motion condition or the simulator training? Table 5 summarizes the findings.

Table 5. Study V: Motion vs. No-Motion BFM Fighter Maneuvering

	No SAAC	No Motion	Motion
<b>a. Mean Performance Ratings for BFM Maneuvers</b>			
Initial Simulator		3.94	3.93
Final Simulator		4.85	5.45**
Initial Aircraft	4.003	3.73	3.64
Final Aircraft	4.89	4.56	4.47*
Overall Aircraft	4.44	4.20	4.13
<b>b. Mean Performance Ratings for BFM Skills</b>			
Initial Simulator		5.65	5.02**
Final Simulator		5.58	6.49**
Initial Aircraft	5.17	4.79	4.96
Final Aircraft	5.22	5.24	5.19
Overall Aircraft	4.98	5.12	5.12

\*\*p < .05.

\*p < .10.

The results of the analyses indicated:

1. No initial difference in performance between the three groups.
2. Significant improvement by all three groups on the task performance variables and consistent but non-significant improvement on the skill set of variables.
3. Superior performance by the control (i.e., no SAAC) group on the task performance variables at the end of the four missions. No reliable differences between groups on the skill variables was observed. The superiority of the Control group was due to a significant difference on the Quarter Plane and small differences on six of the remaining tasks.
4. Considering the overall mission performance ratings, there were no significant differences between the groups.

The dominant conclusion to be drawn from these data is that the simulator pretraining did not result in positive transfer of training. Indeed, there were some indications of negative transfer.

Since there was no positive transfer of training, the findings of this study really do not bear on the motion issue. There is clearly a need to develop training methodologies which result in effective use of simulator training for air-to-air combat skills. The subjective opinions of the IPs who served as simulator instructors reflected a concern that effective instruction from the position of flying the other cockpit was, at best, difficult. The fact that their ratings indicated learning had occurred may reflect their bias that learning *should* have occurred. In the absence of some other form of independent measurement, it is impossible to ascertain whether the students did acquire relevant skills that transferred but were not measured, whether the acquired skills were not relevant, or whether a measurement bias occurred. Thus, since no baseline for transfer of training was established, the comparison of the platform motion contributions toward the enhancement of that transfer is a moot question.

### Study VI: Motion vs. No Motion: Air-to-Surface Weapons Delivery (Gray & Fuller, 1977)

Study VI was designed to investigate the extent to which simulator pretraining could facilitate the acquisition of conventional air-to-surface (A/S) weapons delivery skills. Included in this objective was the attempt to investigate the relative effectiveness of the simulator training for pilots of varying ability levels. The secondary objective was to assess the contribution of platform motion cueing. This study is different from the other studies reviewed in this report because the simulator pretraining was given in the ASPT configured as a T-37 and the criterion aircraft was the F-5B (i.e., generalized transfer rather than specific transfer).

#### Method

A total of 24 pilots participated in the experiment. The participants were assigned to groups on the basis of matched ability level as determined by their performance at fighter lead-in training at Holloman AFB. The sample was also screened on the basis of prior flying experience so that all participants had only UPT and fighter lead-in training experience. They received the full complement of lead-in training experience in the T-38 except for two sorties dealing with weapons delivery. These sorties were deleted from their lead-in training and replaced with two F-5B sorties.

The subjects were assigned to either a Motion, No-Motion, or Control group (eight per group). All subjects received a block of ground school classroom instruction concerning weapons delivery procedures and a second block of ground schooling which consisted of cockpit (F-5B) familiarization and critical emergency procedures training.

The experimental groups received six ASPT missions during which time instruction was given on three bomb delivery tasks, 10 and 15 high drag and 30 dive bomb. Each student received a fixed number of trials on each event. Wind speeds and directions were introduced on the fourth simulator mission. The last two missions were designed to duplicate the same scenario as would be used on the aircraft evaluation flights. As in the earlier studies, all training was given either with or without platform motion cueing. However, the C-seat was fully operational for both groups throughout the ASPT training. F-5B qualified instructor pilots from the 125th Tactical Fighter Training Squadron, Williams AFB, served as simulator and aircraft instructors.

Transfer evaluations took place in the F-5B aircraft. All students received two sorties, each consisting of nine bombing patterns, one practice pattern per task (10, 15, 30 dive angle deliveries) and two bomb deliveries per task.

#### Results

Both experimental groups were superior to the control group on bomb deliveries scores (circular error and number of qualifying bombs) and tended to be rated higher (but not significantly, so) on pattern performance by the IPs. There were no differences between the performances of the Motion and No-Motion groups on either bomb delivery scores or IP ratings in the simulator or in the aircraft.

The results of this study indicate that effective transfer of training on these tasks does not require a high fidelity simulator. The magnitude of transfer probably would have been higher if a F-5B simulator had been used, however, the fact remains that effective transfer was obtained from a completely dissimilar aircraft type simulator.



Another point should be made with respect to the results of the generalized transfer effectiveness. The results of the bomb delivery scores themselves were relatively clear. However, the IP ratings revealed only a trend ( $p < .20$ ), in favor of the ASPT trained group, not at a level of conventional statistical significance. The ASPT trained pilots must have been doing something better in order to deliver bombs closer to the target, yet the IP ratings did not reliably reflect it. This points to the difference between dependent measure types and the fact that the magnitude of an effect must be considerably larger to be reflected in rating scale type scores.

With respect to the motion/no motion question, several points need to be made. Although there was no evidence indicating a difference between the performance of those pilots trained with platform motion versus those trained without it, this finding could be attributable to the presence of G-seat cueing for both ASPT trained groups or the dissimilarity between simulated T-37 motion cues and in-flight F-5B cues. It could be the G-seat cueing was sufficient or that the presence vs. absence of T-37 type cues is totally irrelevant to the use of F-5B aircraft motion cues.

Table 6 presents some of the data obtained on two F-5B aircraft evaluation sorties. The mean circular error per task per group summed across both sorties is presented. The higher the number, the farther the bomb hit from the target. The Motion and No-Motion were not found to be reliably different from each other, but both groups were significantly better than the Control group.

Table 6. Bomb Deliveries — Aircraft Mean Circular Error: Study VI

	Bomb Delivery Circular Error, Feet		
	10° dive angle	15° dive angle	30° dive angle
Control	200	180	204
Motion	148	138	169
No-Motion	138	144	159

#### IV. DISCUSSION

The objective of the line research summarized in this report was to assess the differential transfer value of a modern platform motion system on the acquisition of flying skills. Prior to initiating the studies, the expectation was that the 6 DOF system would significantly enhance transfer to the aircraft. The main question of interest was thought to be the magnitude of that effect, whether the effect would be sufficient to justify the cost, or whether a less costly system, such as a G-seat (and/or G-suit), might be more cost effective.

This set of expectations was derived from the results of a number of lines of motion related research such as single-axis tracking tasks, comparisons of pilot control inputs in a simulator with those in an aircraft, the result of simulation in the design of an aircraft, and human engineering of various instrument displays. Moreover, there was (and is?) a commonly held belief among pilots that some form of motion cueing was required in order to enhance realism, thereby increasing pilot acceptance of simulator training. Relatively little was known about the relationship between pilot acceptance and training effectiveness.

This report has summarized the design, conduct, and results of six transfer-of training studies in which the presence of platform motion cueing was compared to the same training in the absence of platform cueing on the acquisition of various contact flying skills. Table 7 summarizes the six studies reviewed. The series of studies falls short of the original plan in that no work was conducted on the larger tanker-transport-bomber type of aircraft, only low and intermediate pilot experience levels were used, and a limited amount of work was accomplished in the advanced tactical skill area.

Given the intent, the results, and the limitations of these studies, a number of summary questions need to be addressed:

1. What do we now know about the training effects of platform motion cueing that was not known before?
2. Are the findings of these studies consistent with the previously available information?
3. What recommendations regarding improving training programs and future research areas can be made as a result of this research?

#### Platform Motion and Training

Simulator training with platform motion cueing did not significantly enhance subsequent performance in the aircraft for the beginning Air Force pilot in the basic instrument contact task/skill area. This result was not dependent on the field of view in the simulator.

The impact of platform motion cueing on the acquisition of advanced contact skills remains largely undefined. Although a large positive training effect was demonstrated in the area of conventional bomb delivery, the dissimilarity between the simulator motion model (T-37) and the aircraft motion system (F-5B) clouds the issue with respect to platform motion. A low level of transfer was obtained in the area of UPT aerobatic tasks and essentially no transfer was obtained in the basic fighter maneuvering skill task area.

Simulator motion cueing does not consistently impact skill acquisition in the simulator. Only one of six studies reported a motion positive effect, but the magnitude of the effect accounted for less than 6 percent of the non-error variance.

No evidence of motion-related negative transfer was obtained in any of the studies. Additionally, the motion trained groups did not do worse than the no-motion groups. Thus, there is no reason to believe that motion has any detrimental effects.

In summary, the expectation that platform motion would significantly facilitate skill acquisition was not confirmed.

#### Relevance to Previous Research

A review of the literature indicates that the strong positive motion bias reflected in the initial set of expectations is not well founded on the basis of existing data. This is particularly true for the training research relating to skill transfer from simulator to aircraft. While a comprehensive review of the literature is not within the scope of this paper, a few summary statements can be made. The interested reader is referred to Cyrus (1978), Puig, Harris, and Ricard (1978), and Waag (1989).

Table 7. Study Summary

Study	Simulator	Aircraft	Pilot Type	Task Type	Motion Effect	Transfer Effect
1. Martin and Waag, 1978a	ASPT/T-37	T-37	Pre-Solo UPT	Basic Contact	No	Positive
2. Martin and Waag, 1978b	ASPT/T-37	T-37	Post-Solo UPT	Acrobatics	No	Marginal Positive
3. Natanovsky, Waag, Weyer, McFadden, and McDowell, 1979	ASPT/T-37	T-37	Pre-Solo, UPT	Basic Contact	Yes - ASPT No - T-37	N/A No Control
4. Woodruff, Smith, Fuller, and Weyer, 1976	ASPT/T-37	T-37	T-37 UPT	All T-T-37 Tasks	No	Positive
5. Pohlman and Reed, 1978	SAAC	F-4	RTU	Basic Fighter Maneuvers	Yes - SAAC No - F-4	Marginal Negative
6. Gray and Fuller, 1977	ASPT/T-37	F-5	UPT/FLIT Graduates	Conventional Bombing Tasks	No	Positive

In a conservative sense, it can be said the results of these studies neither support nor refute any previously existing data since they are the only transfer-of-training studies done on a modern full mission simulator investigating the variety of contact tasks included in this series. However, the point needs to be made that previous motion-related research has either dealt with tasks not representative of flying or has been done with far less sophisticated equipment on instrument tasks or has been a study of performance in a simulator only — not addressing transfer to the aircraft. There are two areas of research which most clearly indicate the potential usefulness of motion cueing: tracking tasks and evaluation of instrument displays. It is primarily these data which are referenced as documenting the need for motion cueing for training.

Considerable data collected on single- or dual-axis compensatory or pursuit tracking tasks seems to indicate that roll motion cueing can lead to improved tracking performance when higher frequencies (3 rad/sec) are used, a condition which is used as an abstraction of a marginally stable aircraft. The effect is seen in increased lead compensation, a control pattern which should be useful when controlling a marginally stable aircraft. This type of result has been shown to be a function of the number of axes used, the presence of additional visual cues, and the complexity of the plant dynamics.

It is debatable whether a compensatory tracking task has anything in common with most flying tasks except during an early stage of skill acquisition, or whether the plant dynamics used have anything in common with aircraft dynamics. In addition, the size of the motion related effect (when found to be statistically reliable) is typically small, accounting for less than 10 percent of the non-error variance. Compared to the magnitude of the variance accounted for by individual differences (approx 30 to 50 percent), the motion effect is often trivial (see Cyrus, 1978). However, two aspects of this area of research are important for interpreting the present studies: (a) almost none of the tasks investigated involve the control of a marginally stable or unstable aircraft, and (b) if the size of the motion effect, when present, is as small as found in much of the tracking literature, it is extremely unlikely that any of the present studies would reveal it in a statistical sense.

Another research area which has contributed to the pro-motion position is the simulator evaluation of alternative instrument display configurations. The findings of an early study in this area (Douvillier, Turner, Mclean, & Heinle, 1960) investigating attack displays were interpreted to indicate that performance in a simulator with pitch and roll motion cueing more closely resembled performance in the aircraft than did performance in a fixed-base device. Similarly, research conducted at the Aviation Research Laboratory on various instrument display mode variables indicated that simulator motion reliably influenced the use of the displays in such a way to make the motion condition most typical of aircraft performance (see Jacobs, Williges, & Roseoe, 1973; Johnson, Williges, & Roseoe, 1971). From this line of research, it appears that the evaluation of new instrument displays can be significantly influenced by motion cueing and that efforts in that area need to take into account the factors which will make performance in the simulator more representative of performance in the aircraft. These findings are viewed as being neither consistent nor inconsistent with the studies in this report.

Surprisingly little research related directly to the question of motion and training has been conducted prior to the present studies. Using a CAT-2 trainer, Koonce (1974) found that simulator performance was influenced positively by motion cueing (2-1/2 DOF, sustained and washout types) on instrument tasks but that the difference did not transfer to the aircraft. In fact, the group trained without any platform motion actually performed better in the aircraft than did the motion groups. In a subsequent study using the same device, Jacobs and Roseoe (1975) found that normal washout cueing resulted in only marginal simulator performance improvement over random motion cueing on instrument tasks and that the normal motion groups did only slightly better than the no-motion condition. Based on these studies, it is apparent that the motion cueing would not be expected to result in substantial training benefits (in terms of enhanced skill

or time savings) for instrument training. However, at that point in time, it was expected that more sophisticated systems would enhance the behavioral effect.

Although there is little data supporting the need for platform motion cueing in the training domain when a broad range of tasks is considered, there are areas where some cueing is thought to be beneficial. In a study demonstrating the potential usefulness of motion cueing for training specific tasks not trained in the aircraft, DeBerg, McFarland, and Showalter (1976) reported that motion cueing resulted in better recovery from an outboard engine failure after rotation on takeoff than did no motion/no visual only conditions. In this instance, the yaw-related cues were critical in alerting the pilot to the emergency condition. Although a 6 DOF system is probably not required to provide the adequate cues, it is apparent that a motion cue allows for ground-based training of a critical task not practiced in the aircraft.

Despite the enhancement of skill acquisition in the simulator, there is recent evidence to suggest little enhancement of transfer to the aircraft. Ryan, Scott, and Browning (1978) reported a significant reduction in average trials to proficiency for engine aborts on takeoff for P-3 students trained with platform motion (1.5 vs. 3.0 for Abort Four Engine and 2.9 vs. 4.9 for Abort Three Engine). However, there occurred no differential transfer for aborted takeoffs in the aircraft. Likewise, there were no differences for a variety of instrument tasks, landings, and engine failure after refusal.

Caro (1977a) and Caro and Pohlman (1978) have recently criticized much of the motion/training research on the grounds that the research has not focused on the relationship between the motion cues and training objectives. He argues that in order for motion cues to be useful, they must present meaningful information to the pilot. He has used Gundry's (1976) distinction between maneuver motion (i.e., motion which is the result of pilot-initiated changes and is within the control loop) and disturbance motion (i.e., motion which is the result of environmental conditions such as turbulence or the result of a mechanical failure) to argue that maneuver motion (under stable conditions) functions only to provide feedback on pilot induced changes, and that such feedback is also available readily from other sources such as changes in instrument readings and external visual cues. Under stable conditions in which the motion cue is simply one of several available feedback cues, there would be little training value derived from simulating the maneuver motion. It is only under unstable conditions or in instances of disturbance cueing that motion cues are useful sources of information to the pilot. He argues that simulator training with motion cues in these situations should be valuable.

Caro's criticism of much of the available transfer-of-training research, including the studies reviewed in this report, is that they all focus on the maneuver cueing rather than the disturbance cueing type of motion. Indeed, this is the case, and the results of these studies are certainly consistent with the notion that simulating maneuver motion adds nothing to transfer of training. However, it was specifically for the purpose of simulating a broad spectrum of maneuver motion that the modern six post synergistic platform systems were designed and it was specifically with the intent of enhancing transfer of training that such systems have been procured. A 6 DOF synergistic system is clearly not required to provide the types of motion cues that result from disturbance induced conditions. A much simpler and far less costly device would suffice. It was specifically for the purpose of assessing the need for the motion provided by the modern systems that this line of research was initiated.

In summary, the available data indicate that some form of motion cueing can enhance performance in the simulator in specific flight envelopes which represent unstable aircraft conditions. This effect is typically small in magnitude compared with the effects of simulator training in general or the individual differences between the subjects. Despite such enhancement of in-simulator performance, there is no evidence to date which demonstrates increased transfer of training to the aircraft. It would appear that the pro-motion position for training was based primarily on opinion and intuition rather than data.

## Future Motion Training Research

Motion cueing will continue to be a research topic of interest to the R&D community and to the operational force. AFHRL is currently conducting another transfer-of-training study investigating the differential effects of platform motion, G-seat, and G-suit cueing to the acquisition of conversion and surface attack tasks in the A-10 aircraft. Air Training Command is currently conducting a motion study using their Instrument Flight Simulator in which an entire class will be trained throughout the UPT syllabus (T-37 and T-38) either with or without platform motion. This type of operational research needs to be expanded to a variety of weapon systems in order to complete the research cycle. In addition, alternative cueing systems (G-seat and suit) need to be studied.

In addition to continuing the traditional approach, a new approach needs to be developed in which the application of motion cueing is not tied to the physical model (i.e., fidelity model) but to a training model. In such an approach, the software may vary from one task/skill area to another in order to take advantage of the differences between tasks with respect to the motion cues and the information they convey (or can be made to convey) to the pilot. It may then be possible to increase the training value of motion cueing to be derived from already existing systems.

As mentioned earlier, the research reviewed in this report focused on the maneuver-correlated motion cues and did not deal with the value of disturbance cues. The only transfer-of-training study dealing with this category (Ryan, Scott, & Browning, 1978) reported no transfer. Many of the flight circumstances in which disturbance and unstable flight envelopes are encountered would be difficult if not impossible to systematically study using a transfer-of-training methodology. Consequently, it will be difficult to establish the training value of such type of simulator cues. The research strategy required to study the value of disturbance motion cueing should not rely on achieving proficiency in the simulator but should be directed toward establishing the functional information conveyed by such cues. From the engineering side, the minimum hardware required to display the disturbance cues for a given aircraft should be defined.

## V. CONCLUSION

Platform motion cueing has not been shown to enhance transfer of training for novice jet pilots applied to the acquisition of basic contact skills. The findings of the studies reviewed in this report are viewed as being consistent with previously existing data on the transfer of instrument skills. In light of all the available data, the following conclusions are offered:

1. Platform motion has little or no demonstrated positive effect on transfer of training.
2. Platform motion has a small effect on the performance of experienced pilots in the simulator.
3. Platform motion has the most potential for enhancing simulator training on specific tasks requiring control in a marginally stable condition.

The present studies offer little to clarify existing theoretical postulations regarding the interaction of kinesthetic cues and flying skill. The following tentative hypotheses are consistent with available data.

1. Kinesthetic cues of the magnitude produced by off-the-shelf platform systems function as noise rather than meaningful signals to the novice pilot for tasks in which motion cueing is not specifically task relevant.
2. For tasks in which motion cues are specifically task relevant, they function as alerting cues and do not need to be high fidelity in nature.

3. Motion cues acquire information value as a function of experience, can enhance performance, and influence controlling strategies of the experienced pilot.

In this case, it follows that the cues need to be in some sense realistic in order to function as meaningful information. However, the magnitude of the motion related performance effect is not expected to account for a large portion of the performance variation. It also follows that simulator motion functions as a variable which can affect performance but does not influence the learning process.

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